CHAPTER 6

Science, Technology, and the U.S. Economy

TWENTIETH CENTURY ADVANCES in science and technology have brought deeper understanding of the nature of matter and the origins of the universe, the vanquishing of many forms of disease and pestilence, efficient and economical worldwide communications, and human travel to the Moon. For example, the invention of the integrated circuit, with its seemingly unlimited applications, has been compared in importance with Gutenberg's movable type. The revolution in biotechnology, advances in recombinant DNA (deoxyribonucleic acid) research, and other breakthroughs in health technologies promise major advances in the fight against disease.

The United States has been in the forefront of these stunning accomplishments, and the U.S. Government has played a leading role in stimulating and undertaking the research and development needed to achieve them. The government has a keen interest in science and technology, because work in those fields relates directly to national security technologies, and also because the results of such research have significant economic consequences. During the past 8 years, this Administration has sought to reorient direct government involvement in research and development (R&D) and stimulate the forces of the private sector as well.

Advances in knowledge contribute importantly to the Nation's real economic growth; about one-half of all growth in output per capita has been attributed to technological knowledge and managerial and organizational know-how. Estimated rates of return to private industry's R&D spending range from 20 to 50 percent. More importantly, the rate of return to society is about double the private rate. Thus, R&D is a good investment for society. Because the returns to society typically exceed the returns to the sponsor of the research, however, the private sector has inadequate incentive to invest in R&D, particularly where the results cannot be easily appropriated for production and profit. Partly because of this underinvestment, the Federal Government supports R&D.

In short, government policy toward, and support for, scientific research and technological innovation are important for the future of America.

OVERVIEW

The purpose of this chapter is to provide an economics perspective on the debate over the appropriate policies to ensure the continued contribution of science and technology to U.S. economic growth. Like the other chapters of this *Report*, it examines changes in institutions and incentives over the longer term. This chapter does not attempt to provide a comprehensive review of U.S. science and technology (S&T) policy, nor of all the factors that affect the incentives of firms to invest in R&D and to innovate. Instead, it highlights some of the recent changes in U.S. approaches to science and technology.

The chapter first reviews international trends in science and technology that influence the relative U.S. position in science, in technology, and in innovation. It also reviews the U.S. position in the international trade of high-technology products and the role that technology plays in trade relationships. Based on this evidence, some of the fears of a declining U.S. position in science, technology, and high-technology trade are misplaced. Given economic conditions after World War II, the United States was able to become the dominant supporter of R&D, which led to technologically advanced products. As other nations recovered economically, they too began to invest in R&D. Thus, some decline in the relative U.S. position is to be expected. The increasing S&T capabilities of U.S. industrial partners provide an opportunity, as more countries are sharing the costs of technological advances, sharing basic research, and providing benefits to consumers in the form of technologically advanced products. However, those capabilities also present a challenge to American producers. An area of growing concern to U.S. industry, based on its trade performance, is its manufacturing technologies, and industry is taking a variety of steps to remedy its deficiencies. Some of the current policy debate is over the appropriate Federal role in this area.

This chapter also examines the institutions and incentives in the S&T policy environment. It highlights several S&T policy initiatives of the 1980s aimed at strengthening the incentives of U.S. industry to invest in R&D: taxes, antitrust, and intellectual property protection. It reviews the incentives and new institutional relationships that encourage the transfer of research results to industry from the academic sector and government laboratories. The latter initiatives play an important role in facilitating the rapid transfer of science into commercial applications.

Ultimately, for society to benefit from inves nts in R&D, the results must be turned into products, processes, and services—technology must get off the shelf. A major concern is the broad economic benefit of federally supported research. As described in this chapter, a strong technological position by U.S. firms will not keep production from going offshore, but this result does not preclude U.S. consumers and investors from benefiting from that technology. In addition, the U.S. research system is very open. International research collaboration—whether formal or informal—benefits the United States as well as the foreign partners by improving the productivity of the R&D process. Where exclusive property rights to research results can be established, however, the U.S. Government has already taken steps to protect such knowledge.

Recommendations for improving the efficiency and the effectiveness of the R&D and innovation process must recognize the decentralized and competitive S&T system. The system has served the United States well. While the S&T systems of other countries differ in some ways from that of the United States, they are not demonstrably superior. However, the incentives and institutional relationships within the United States need to be examined to ensure that barriers do not inadvertently limit the ability of the public's investment in R&D to benefit the Nation as a whole.

INTERNATIONAL COMPARISONS

The United States continues to be a leader internationally in science, but U.S. firms face strong technological competition from other major industrial countries. Japanese firms are particularly capable in implementing new manufacturing processes and in commercializing technologies.

SCIENCE AND TECHNOLOGY INPUTS

Chart 6–1 characterizes the national R&D effort by source of funds, performer, and character of work (basic research, applied research, and development). This chart provides background for the discussion in this section.

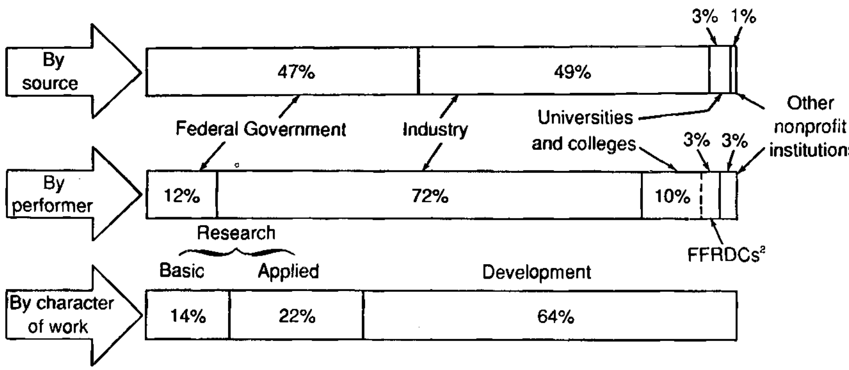
Aggregate Research and Development Spending

Total U.S. expenditures on R&D, adjusted for inflation, have grown dramatically since the 1950s. Real spending (in 1982 dollars) grew from $20 billion a year in 1953 to $104 billion in 1987. National R&D funding trends for France, West Germany, Japan, the United Kingdom, and the United States for the period 1965–86 are shown in Chart 6–2. In 1986 the United States spent more on R&D than France, West Germany, Japan, and the United Kingdom combined.

Chart 6-1

The National R&D Effort

Expenditures for research and development=$124.9 billion, Fiscal Year 1988[1]



[1]Estimated.

[2]Federally funded research and development centers administered by universities and colleges.

Source: National Science Foundation.

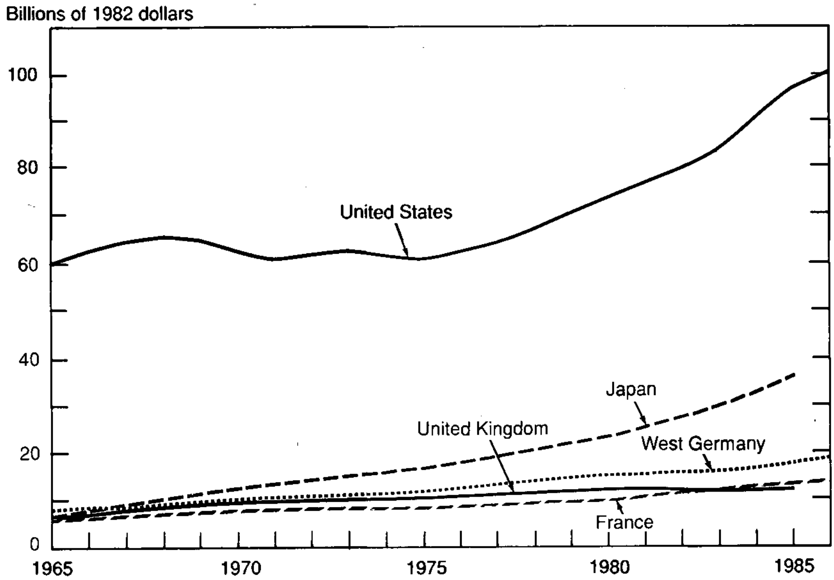
However, the U.S. share has declined; 20 years earlier, U.S. expenditures were more than twice the size of the combined expenditures of those four countries.

Japan, West Germany, and the United States now spend roughly the same proportion of their gross national product (GNP) on R&D. Estimates for 1986 (the latest year for which data are available for all countries) show that Japan devoted 2.8 percent of its GNP to R&D, while the United States and West Germany each spent 2.7 percent. Despite steady growth in non-Federal R&D, declines in the ratio of R&D to GNP in the United States have resulted from lower Federal R&D spending on defense and space. For example, the U.S. ratio peaked at 2.9 percent in 1964 and dropped between 1968 and 1979, reflecting the decline in Federal R&D for defense and space. West Germany and Japan have the highest percentages of GNP devoted to nondefense R&D expenditures. Japan's ratio stood at 2.8 percent in 1986, compared with 2.5 percent for West Germany and 1.9 percent for the United States. Based on absolute amounts of nondefense R&D funding, however, the United States still outspends these two industrial competitors.

But which measure of national R&D spending determines technological capabilities: absolute levels of spending or share of GNP? For

Chart 6-2

National R&D Expenditures, Selected OECD Countries



Note.— Dollar conversions are based on OECD purchasing power parity exchange rates and U.S. Department of Commerce GNP implicit price deflators. Data for 1984-86 are preliminary or estimated. Data for United Kingdom are not available for 1965; 1964 data used.

Sources: National Science Foundation, Organization for Economic Cooperation and Development, and national sources.

some purposes, absolute R&D spending levels may well be more relevant in providing benefits to society. The basic output of R&D is knowledge, which can be spread over any number of units of output; increased production may require no additional knowledge. But comparisons of absolute levels of spending are also limited. One problem is that new knowledge is not equally relevant to all sectors of the economy. Because knowledge relevant to one industrial sector, such as pharmaceuticals, may not be applicable to another, such as electrical machinery, a more diverse economic base may require more R&D to sustain the pace of technological innovation across all sectors.

Major changes in a country's ratio of R&D to GNP do indicate a shift in the emphasis that the country places on R&D. The full significance of that shift in emphasis, however, depends on where the reallocated funds are spent.

Industrial Research and Development

Industry supports a major share of national R&D in the five industrial nations examined here. Furthermore, industry's share increased over the 1970–86 period. Industry in Japan supports the largest share of national R&D (69 percent in 1986), followed by West Germany (61 percent that year). In the United States, industry funds roughly one-half of all R&D.

Across the five countries, the industrial sector receives varying amounts of government R&D funds. For those countries with major expenditures on defense R&D, government provides a greater share of industrial research and development. Thus, in the United States, the government finances one-third of industrial R&D. In contrast, Japanese companies fund 98 percent of all industrial R&D, and West German companies support more than 80 percent of their own R&D effort.

Comparisons of business R&D (conducted with both private and government funds) show some differences in national emphases on broad manufacturing sectors. All five nations emphasize the electrical equipment industry (excluding computers). France, the United Kingdom, and the United States also particularly emphasize aerospace.

These comparisons are based on distributions of each nation's spending in the industrial sector, not on funding levels that more directly affect technological capabilities in particular sectors. Nonetheless, the relative emphases within a nation identify what sectors it views as important and, to the extent that R&D-intensive products are internationally traded, where competition is likely to lie and gains from trade are most likely to occur.

Scientists and Engineers

Both the United States and Japan send a much larger proportion of their young adults to college than do France, West Germany, and the United Kingdom. Similar proportions of American and Japanese college-age populations receive first university degrees (25.9 percent for the United States and 22.6 percent for Japan in 1986), while fewer than 10 percent do so in the other three countries. Japanese universities award a somewhat larger proportion of their degrees in the natural sciences and engineering (27 percent of all degrees compared with 20 percent in the United States). Significant differences arise, however, between the two countries in fields of emphasis. Almost three-quarters of all Japanese students in science and engineering are in engineering, while slightly more than one-third of such American students obtain engineering degrees.

The United States has the largest concentration of scientists and engineers engaged in R&D, as a proportion of its labor force, followed closely by Japan. Between 1965 and 1986, the other four nations increased their relative use of scientists and engineers to perform R&D, while U.S. employment of R&D scientists and engineers as a share of the labor force reflected fluctuations in the ratio of R&D to GNP. The absolute number of U.S. scientists and engineers engaged in R&D has been increasing since 1973, however, giving the United States a large base of R&D personnel.

SCIENCE AND TECHNOLOGY OUTPUTS

Policymakers are interested in the S&T system because of its generation of knowledge and ideas and the linkages between science and technology. Several indicators of these outputs are available, although they are only proxies for, not direct measures of, the knowledge and ideas generated.

Nobel Prizes are a well-known indicator of scientific achievement. Since 1945 U.S. citizens have received about 50 percent of such prizes awarded in science. Based on where the research was done, the United States has hosted an even larger fraction of the prize-winning work over the past four decades. But the Nobel Prize is not a good indicator of the current strength of science in a nation because the award lags the performance of the work by years, even decades. On a per capita basis, of the nine countries whose citizens have received the most Nobel Prizes in science since 1970 (population in 1980), the United States ranked sixth, behind Sweden, Denmark, Switzerland, Belgium, and Great Britain; Japan ranked ninth, behind West Germany and France.

Citations or references to papers and patents are one indicator of the influence or importance of the cited paper or patent. Based on citation measures, U.S. scientific research is of very high quality. The U.S. share of citations made in a large set of scientific journals published worldwide was about 40 percent higher than the U.S. share of publications in that set.

Patent Shares

Because a patent protects an invention only in the country in which the patent is issued, foreign filings for U.S. patents are indicators of potential foreign competition. As might be expected when other nations increase their research capabilities, the U.S. share of some S&T outputs has fallen. The U.S.-invented share of U.S.-issued patents has fallen from 73 percent in 1970 to 52 percent in 1987. This declining share also reflects an 8 percent fall in the actual number of patents granted to U.S. inventors, even though total U.S. patents granted increased 29 percent. Japanese inventors have increased their share of patents received fivefold, more than the inventors of any other country. Their share of U.S.-issued patents increased from 4 to 20 percent.

Links Between Science and Technology

Although science generates knowledge used for commercial applications, that linkage can be difficult to identify and quantify. One approach to quantifying this relationship identifies the use of academic research in industry and the value of the time that such research saves a firm in its innovation process. Based on this measure, the contribution of academic research to industry is large; using conservative assumptions, the social rate of return is estimated to be at least 28 percent.

Another approach is to examine the connections by using publications as a proxy for science and patents as a proxy for technology. Citations from patents to the scientific literature help to establish links between science and its technological applications. In general, however, the knowledge most frequently cited by patents is contained in other patents. The patents described here are those issued by the U.S. Patent and Trademark Office to residents of various countries, and the references are those cited by the U.S. patent examiner. Before granting a patent, the patent examiner must identify the prior art, i.e., the knowledge at a particular time that determines whether an invention is new and not obvious to someone with normal skills in that area.

The science intensity of inventions from the five major industrial countries has been increasing, as measured by the average number of scientific publications cited per patent filed in the United States. Between 1975 and 1986, patents issued to U.S. inventors have grown most rapidly in science intensity. The science intensity of Japanese patents is now the lowest of the five countries, suggesting that advances in Japanese technology are based on improvements in other patented technologies. At the beginning of the period studied, patents of inventors from the United Kingdom were the most science-intensive, but patents of U.S. inventors overtook them in 1980.

Earlier studies of the connections between the development and application of scientific knowledge found lags exceeding 20 years, but some evidence now suggests that the lag is shrinking. Patent filings are showing a much shorter time between publication of research results and their incorporation into a patentable technology: science is being applied sooner. The median age of scientific publications cited in U.S.-issued patents over the 1975–86 period has been declining for all five countries. Throughout the period, patents issued to U.S. inventors have cited the most recent publications, followed by patents issued to Japanese inventors. West Germany has consistently cited the oldest publications. In 1975 the median age of publications cited by U.S.-owned patents was just under 8 years; by 1986 the median age was slightly more than 6.5 years. In some rapidly growing fields such as biotechnology, recent patents cite research, including basic research, of about the same age as the literature cited in research articles on bioscience.

INDUSTRIAL INNOVATION IN THE UNITED STATES AND JAPAN

Before society benefits from the full value of R&D spending, the knowledge gained must be converted into products, processes, and services. Thus, the factors involved in this conversion are an important component of any comparison of innovative capabilities.

For the manufacturing sector overall, Japanese and American firms that do R&D spent roughly the same proportion of net sales on R&D in 1985 (2.7 percent in Japan versus 2.8 percent reported for company-funded R&D in the United States). Within manufacturing, however, the ratios of R&D to net sales vary. For example, ceramics and iron and steel are more R&D-intensive in Japan, while the professional and scientific instruments sector is significantly more R&D-intensive in the United States.

Recent studies show that American and Japanese firms devote similar proportions of their R&D expenditures to relatively risky projects (about one-quarter of their R&D to projects with less than a 50 percent estimated chance of success) and to long-term projects (almost 40 percent of R&D to projects expected to pay off after 5 years). This similarity represents a significant shift for the Japanese from the 1970s, when Japanese industrial R&D was composed largely of low-risk and short-term projects. Japanese firms appear to have changed both the breadth and depth of their R&D and in these ways more resemble American firms.

Nonetheless, differences remain in the composition of American and Japanese industrial R&D. The U.S. firms studied devote about two-thirds of their R&D expenditures to product technology (new products and product changes) and about one-third to process technology (new processes and process changes). Japanese firms reverse the proportions. This difference cannot be attributed simply to different industry mixes at the aggregate level. Within the chemicals industry, where firms in both countries emphasize product innovations more than does the sample as a whole, U.S. firms still devote a greater share of their R&D to product than to process innovation than do the Japanese.

American and Japanese firms need about the same time and incur similar costs to carry out innovations based on technologies developed within the firm. Recent work suggests, however, that Japanese firms enjoy advantages over U.S. firms with respect to innovations based on external technology, that is, technologies originating outside the firm. Many innovations based on external technology involve new products that imitate others in important respects. The contrast between Japanese and U.S. firms shows up particularly in the commercialization stage of the innovation process (beginning when the product is developed and ending when it is introduced commercially), as distinguished from the R&D stages. In the United States the commercialization of an innovation based on external technology requires more time and about as much money as the commercialization of one based on internal technology. Japanese firms, however, are able to commercialize innovations based on external technology faster and at less cost than those based on internal technology.

Japan's advantage here depends on how many U.S. innovations are based on external technologies. However, modifications of external technologies are reported to be an important source of U.S. innovations. Efforts of Japanese firms to improve their S&T capabilities largely involved catching up with U.S. firms. In these circumstances, their greater efficiency in adapting external technology affords a clear advantage. Yet this superior efficiency of Japanese firms in commercializing external technologies does not appear to be attributable solely to the advantages of being a follower. In carrying out such innovation, they have been more likely than American firms to adapt the imitated product significantly and reduce its production costs substantially. The Americans seem more inclined to invest heavily in marketing startup costs, emphasizing marketing strategies more than technical performance and production cost.

The ultimate arbiter of the value of R&D strategies is the market. Before examining how U.S. firms have fared in international high-technology trade, however, a look at how the U.S. and Japanese governments develop their S&T policies—policies that influence the S&T capabilities of industry—is in order.

GOVERNMENT RESEARCH POLICY IN THE UNITED STATES AND JAPAN

The Japanese government accounts for only 21 percent of its nation's R&D funding, but it nevertheless plays an important role in science and technology. It identifies new directions for R&D efforts and encourages R&D initiatives by industry through financial incentives, selective R&D funding of particular R&D projects, and the creation of special institutes. Japanese S&T policy develops from consultation and consensus. The Council for Science and Technology, the primary authority for developing Japanese S&T policy, recommends long-term national policy objectives but funds no R&D. It recently identified the need for a basic shift in emphasis toward seeking creative, fundamental breakthroughs that benefit not only Japan but also the international community. Its latest recommendation stressed basic research, greater involvement of foreign researchers, and industry and university cooperation.

Almost one-half of the Japanese Government's S&T budget (which includes some expenditures that do not meet the narrower definition of R&D) in 1985 went to the Ministry of Education, Science, and Culture (Monbusho), which administers Japan's national universities and their affiliated research institutes. The Japanese approach (also used in many European countries) provides long-term government support to public universities for faculty R&D activities. In contrast U.S. Government agencies fund most university research on a shorter term and competitive basis.

With 27 percent of the government's S&T budget, the Science and Technology Agency funds and conducts basic and applied research. It also directs the Japan Research and Development Corporation, which encourages the commercialization of promising R&D developments at the national universities and research institutes.

The Ministry of International Trade and Industry (MITI) spent 13 percent of the government's 1985 S&T budget. While MITI wielded substantial power over Japanese industry during the 1960s and early 1970s, controlling foreign exchange, technology licensing from abroad, and tariffs, it has largely lost those powers. Currently, MITI tries to influence the private sector through using its R&D funds to leverage higher industrial R&D funding. Within MITI, the Agency for Industrial Science and Technology (AIST) sponsors development of technologies with potential commercial value, much of which is carried out in AIST-administered national and regional industrial research institutes. The AIST also administers special incentives, such as conditional loans (which are included in the S&T budget) and tax deductions for private-sector technology development.

The two countries also differ in how they carry out long-term S&T planning. The Japanese Government has conducted major formal forecasting exercises that included large sections of the industry, government, and academic communities in the forecasting process. Every 5 years Japan's Science and Technology Agency sponsors these forecasts, which combine the "science push" and "demand pull" perspectives on technological innovation. Among the areas ranked highest in terms of future Japanese S&T needs in the most recent survey are cancer; storage and disposal of radioactive solid wastes; automatic protocol conversions to facilitate information flows between communication networks; advanced software verification technology for rapid development of error-free, large software systems; antivirus agents for treatment of viral diseases; and industrial application of superconducting materials.

The accuracy of forecasts that reach 30 years into the future is open to question, particularly where unforeseen developments may change opportunities. Nonetheless, the Japanese forecasts help establish R&D priorities. Furthermore, some observers say that thinking about longer term applications encourages Japanese industry to monitor external research and more quickly adopt the findings.

It is not necessarily advisable, however, for the United States to make its own 30-year forecasts. Such forecasts tend toward conservatism, fail to anticipate some of the more creative scientific advances, and may lead to a consensus that encourages an excessively narrow R&D focus. Rather, the decentralized U.S. system might benefit more from involving potential users of basic and applied research in an R&D agency's process of planning and setting priorities.

HIGH-TECHNOLOGY PRODUCTS AND U.S. TRADE

A product's life cycle and its manufacturing process affect its producer's ability to compete. The importance of performance versus cost characteristics for marketing a product varies with the stage of its life cycle. At the initial innovation stage, the producer's technological lead is the key factor in determining its competitive position. As the initial demand is met and more competitors arise, cost and quality become much more important in generating sales. The location of production can change during the stages of the product life cycle. At the initial R&D stages, the availability of skilled technical labor is important. Later, R&D inputs become less important, and the usual determinants of production location come into play: wages, taxes, transportation, and access to markets. In rapidly changing technologies, a product may never get to the mass production stage, or only be mass-produced for a short time. Thus, the ability to shift quickly to another product can be a critical competitive strategy.

Judging from the success of U.S. multinational firms in maintaining world market shares, the diminished U.S. trade position may result less from deficiencies in American technological leadership than from other factors—productivity, wage rates, taxation, cost of capital, domestic inflation, and exchange rates. As described in earlier chapters, many of these factors that affect cost and quality have recently become more favorable to U.S.-based production. American firms need a policy environment that helps them to benefit from the use of their technologies wherever they produce. Improved protection of intellectual property in countries where such protection is weak can help U.S. firms in this regard, and it can also encourage increased U.S. investment in those countries.

CHARACTERISTICS OF THE HIGH-TECHNOLOGY SECTOR

No commonly accepted definition of high-technology industries exists. These industries are said to make significant use of scientific, engineering, and other technical personnel and to invest in a greater than average level of R&D funding, adjusted for industry size. A definition of high-technology industries based on these R&D-input criteria thus include industries that may differ in market structure, labor composition and compensation, type of product, and the degree of economies of scale. High-technology industries thus defined may also vary substantially in rates of employment and output growth. One study of the 1976–80 period found that some high-technology industries experienced employment growth in excess of 75 percent, while other industries contracted their work force by 50 percent. Several industries with rising levels of output showed slow or negative employment growth.

U.S. TRADE IN HIGH-TECHNOLOGY PRODUCTS

Some research distinguishes between the competitive position of U.S. firms and that of the United States as a geographic location for production. Companies that become multinational in their operations reduce to some extent their dependence on home-country determinants of competitiveness. If home-country production becomes more expensive relative to foreign production because of rapid inflation at home, because the exchange value of the home country's currency has risen, or because labor has risen in price or decreased in efficiency, the multinational firm has some opportunity to shift its production to locations in other countries.

The export shares of all U.S. firms and U.S.-based multinationals were about equal in 1966 (about 17.5 percent of world exports), but the multinationals subsequently maintained their share while that of U.S. firms as a whole declined (to 14 percent in 1984), particularly during the early 1970s. The parent firms of the U.S. multinationals did not escape the forces that led to the fall in the U.S. export share, but they fared better—the fall in the parents' share was less than that of all U.S. firms. The success of exports from their foreign affiliates was largely responsible for maintaining the multinationals' share of world exports.

The distribution of exports among industries reveals the comparative advantages of the United States and its multinational firms. If the multinationals' share of exports in an industry exceeds the export share of all U.S. firms in that industry, U.S. multinationals are regarded as having a comparative advantage in that industry relative to the United States as a country. Among the major industry groups, the multinationals showed such comparative advantages in chemicals, electrical machinery, and motor vehicles. Such advantages change with the exchange rate and differences in productivity growth at home and abroad.

Both R&D intensity and advertising intensity (i.e., marketing) seem to be major factors in the comparative advantage of U.S. multinationals. Many studies associate R&D intensity with the comparative advantage of the United States as a country, and the same R&D intensities are even more strongly related to the comparative advantage of U.S. multinationals.

The United States is relatively less export-oriented than other industrial nations within the Organization for Economic Cooperation and Development (OECD). It has a large domestic market, and its shares of OECD production substantially exceed its shares of OECD exports. The United States also accounts for large shares of OECD production across all sectors, even in those for which, based on the structure of exports, it has no apparent comparative advantage.

High-technology goods account for an increasing share of U.S. trade. Between 1981 and 1987, the high-technology share of U.S. exports of manufactures rose from 35 to 42 percent, and the high-technology share of imports increased from 22 to 25 percent. During the 1980s the combination of slower growth of U.S. exports of high-technology products and the steady increase of such imports led to a dramatic decline in the U.S. high-technology trade surplus. The sectoral trade balance dropped in current dollars from $26.6 billion in 1981 to $3.6 billion in 1985, and to a deficit for the first time of $2.6 billion in 1986. In 1987 the trade balance in the high-technology products sector became positive again at $0.6 billion. Despite this decline, U.S. trade performance in high-technology manufactures has been stronger than in less technology-intensive products. The U.S. trade balance in manufactures that are not high technology continued to deteriorate, going from an $11.2 billion deficit in 1981 to a $138.3 billion deficit in 1987 despite the recovery in exports in 1986 and 1987.

The product groups making up the high-technology sector in these trade statistics are defined at the three-digit standard industrial classification level. While these measures use a definition of high-technology goods that takes into account use of R&D-intensive inputs, each group contains products of varying levels of technological sophistication. Thus, a declining trade balance in a particular product group may in fact reflect an increase in imports of the less sophisticated goods in the product group, rather than changes in the most technologically advanced products. An illustration of this effect is the large increase in U.S. imports of telecommunications products following the deregulation of the telecommunications industry and the breakup of American Telephone and Telegraph on January 1, 1984. Far East nations other than Japan accounted for almost 30 percent of U.S. imports of telephone and telegraph equipment in 1986, and these countries supply mostly low-cost, low-technology telephone instruments.

The emergence of the East Asian newly industrializing economies (NIEs) as major suppliers of products at the low-technology end of high-technology product groups has eroded the U.S. surplus in high-technology trade. American imports of high-technology products from the East Asian NIEs grew faster between 1980 and 1986 than overall U.S. imports of high-technology products. In 1986, East Asian NIEs accounted for about 18 percent of U.S. imports of these products, making these countries key participants in U.S. high-technology markets.

The semiconductor market illustrates the complexities of identifying the role of technology in U.S. competitiveness. Semiconductors are diverse products, ranging from standardized commodity chips to chips custom-designed for specific applications. Technological forces have dictated marketing strategies since the beginning of the industry. The average useful life of many of these products is short. For example, the product life cycle for dynamic random access memory (DRAM) chips has been about 3 years since the early 1970s. Another characteristic of the semiconductor industry is rapid price reductions.

Several factors complicate any assessment of the competitive position of the United States or of U.S. firms in semiconductors. Trade data reflect intracorporate trade in both imports and exports; U.S. offshore manufacturing, primarily in Southeast Asia, generates about one-half of U.S. trade in semiconductors. In addition, some of the largest U.S. producers consume their output internally, and reliable production data are difficult to obtain for such captive producers. In 1978, companies headquartered in the United States (excluding captives) produced 55 percent of global semiconductor revenues; in 1986 they produced 40 percent. Shipments from U.S.-based plants (including captives) held steady at nearly 60 percent of global semiconductor shipments until after 1982, but fell to 52 percent in 1985.

Several factors explain most of the U.S. semiconductor industry's losses of market share in the mid-1980s: faster growth of the Japanese home market, which is supplied primarily by Japanese firms; exchange-rate movements; and worldwide overcapacity and aggressive Japanese pricing, reflected in the 1986 U.S. determinations of semiconductor dumping. The U.S. market share has eroded in products that require efficient manufacturing that can be provided by state-of-the-art process technology. The erosion is most extreme in the market for DRAMs, which demand high yields of good chips in large quantities for economic production. By contrast, U.S. companies' market share has held up better where product design and customer relationships are primary and yields and price secondary; examples are microprocessors and microcontrollers and application-specific integrated circuits.

POLICY ISSUES OF THE 1980s AND BEYOND

Over the past 20 or so years, U.S. policies have evolved in light of a growing consensus that spending on science and technology is an investment in the Nation's future. Policymakers in the 1960s and 1970s sought to use S&T to meet national needs, e.g., in health, safety, environmental quality, energy, and transportation, and to foster continued economic growth. Policy debates focused on the role of the Federal Government in meeting these needs, the role of particular sectors such as small business, and the ability to use Federal Government policies to speed commercial implementation of new technologies.

There has been broad endorsement of Federal support for basic research. The Ford and Carter Administrations both adopted the view that the substantial decline in Federal support of basic research since the late 1960s, if allowed to continue, would have grave consequences for the United States. Both Administrations viewed basic research as a long-run national investment, and both backed these views with real growth in Federal basic research budgets. The current Administration continued providing substantial support for basic research, with a 52 percent increase in real expenditures between fiscal years 1981 and 1989 in the civilian agencies and 48 percent growth over all agencies. The Administration reemphasized the importance of basic research with a proposal in 1987 to double the budget of the National Science Foundation (NSF) over 5 years. The Congress supported this effort and increased funding for NSF by 10 percent in fiscal 1989, in excess of the 2 percent overall increase in domestic discretionary spending.

Other Federal policies in the 1970s focused on applied research and development directed at specific civilian technologies. Experience with many Federal Government efforts to accelerate the development of civilian technologies were expensive and unsuccessful in producing commercially viable processes and products (particularly in the energy sector after the decline in oil prices). As a consequence, the major civilian S&T policy initiatives of this Administration and the Congress in the early 1980s moved away from direct Federal intervention at the later stages of the innovation process. Instead, the policy focus has been on stimulating private investments in

R&D through increased incentives provided by taxes, antitrust exemptions, and strengthened protection for intellectual property rights. In addition, the Federal Government has paid increased attention to incentives for commercial use of R&D that it has financed for its own purposes.

During the 1980s there has been greater awareness of the international scope of science and technology. Some policy initiatives have emphasized strengthening protection of intellectual property internationally and the need for international research cooperation. During the latter half of the 1980s, concerns about U.S. competitiveness have also revived interest in direct Federal support of civilian technologies, particularly funding for industrial R&D cooperatives.

Use of government funds to support particular industries or technologies raises questions of how winners and losers are picked and whether R&D investments that industry is unwilling to make are to be encouraged. Complicating the issue is the fact that U.S. taxpayers are already directly funding nearly one-half of the Nation's R&D.

INCENTIVES FOR PRIVATE INDUSTRY

Recent S&T policy initiatives have sought to strengthen private incentives to invest in R&D and innovation, recognizing that the private sector is ultimately the arena in which research results must be commercially implemented.

Taxes

The Economic Recovery Tax Act of 1981 included a temporary 25 percent tax credit for incremental spending by industry on qualified research expenditures, over and above the average level of such spending for the previous 3 years. Some early studies concluded that this tax credit did not have a strong effect on R&D spending. They attributed the weak effects in part to uncertainty about duration of the credit and to the low effective rate of incentive (because credits are only available for increased spending over a rolling base that changes annually). Small business proponents have also pointed out the credit's limited applicability to newly established firms that are just beginning to fund R&D. The credit was to expire in 1986, but the Tax Reform Act of 1986 extended it at a reduced rate of 20 percent. The Congress has again extended the credit through 1989.

Antitrust

Policy debates in earlier years weighed incentives for innovation against the possibility for reduced domestic competition. More recently, policymakers have analyzed antitrust and competition issues in terms of global markets, and they are more willing to permit cooperation in the pre-production stages of research and development.

Cooperative research among firms has been going on in the United States on a limited scale for many years. The National Cooperative Research Act of 1984 enables firms to cooperate on research in the developmental stages before product sales competition occurs. Under the act, industrial research consortia can register their formation with the Department of Justice and the Federal Trade Commission, thereby avoiding treble damages if the joint venture is later found to violate antitrust statutes. Actions under joint R&D ventures are not deemed to be *per se* violations of any Federal or State antitrust laws, but they are to be judged on a rule-of-reason basis. More than 100 such consortia have registered since the law was enacted.

Intellectual Property

The Omnibus Trade and Competitiveness Act of 1988 gives holders of U.S. process patents greater legal rights to block imports or collect damages from persons who import into the United States products produced overseas using—without permission—processes patented in this country. The United States is also pursuing improved protection of intellectual property through its bilateral science and technology agreements, bilateral trade agreements, and, multilaterally, in the Uruguay Round of negotiations under the General Agreement on Tariffs and Trade. Domestically, the Drug Price Competition and Patent Term Restoration Act of 1984 extended the length of patent protection for pharmaceuticals to compensate for regulatory delays in getting them to market.

New technologies sometimes raise questions about the most appropriate form of protection for their underlying ideas. In semiconductor designs, the matter was resolved through creation of special copyright-like intellectual property protection with a duration of 10 years. Incentives in the semiconductor design legislation for international reciprocity in such protection have led to efforts in Japan, the European Community, and the World Intellectual Property Organization to protect semiconductor designs in this way.

Federal patent and copyright protection and State trade secrecy laws encourage private investment in R&D and in commercializing new technologies. Nonetheless, limits to such protections exist that reflect competing social objectives. The patent system guarantees inventors the right to exclude others from unauthorized use of their inventions, but only for a limited time (17 years from the date the patent is issued in the United States) and in return for disclosure. Trade secrecy has an unlimited duration in the United States, but the owner must safeguard the information against disclosure and is vulnerable to those who independently think of the same idea or who obtain it by legal means, such as reverse engineering. Copyright protection extends longer (typically, life of the author plus 50 years in the United States) than patent protection, but it covers only the form of expression, not the underlying concept. Unlike a patent, a copyright is no protection against an independently developed work.

The tradeoff between encouraging creation of knowledge through the grant of exclusive property rights and permitting early and widespread use of knowledge at a low price has been long debated. These tradeoffs between incentives to invest and losses from restricted dissemination are reflected in the limited duration of legal protection given to intellectual property. Concern that firms would use exclusive patent rights to create or extend product monopolies has also led to restrictions on the use of patents, although some scholars have warned that fears of monopoly extension have led to unwarranted restrictions on the legitimate use of patents to capture economic returns attributable to the invention.

Other limitations of intellectual property protection hinge on the subject matter to be protected. For example, many observers view patent protection for manufacturing processes as more difficult to enforce than patents for products. Process innovations are often based more on superior integration of existing elements than on elements that are clearly new, and they may not meet the criteria for patentability. In addition, infringement of process patents is often less easy to detect and to demonstrate than infringement of product patents.

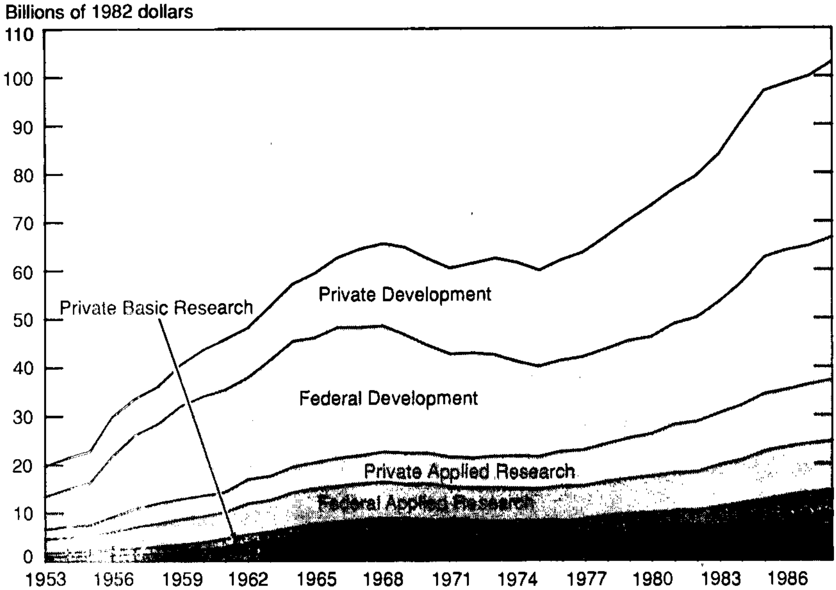
Studies have found variations in the importance of patent protection to firms that innovate; patents are most important for pharmaceutical and chemical companies. The ability to protect intellectual property is not, however, unimportant in providing a competitive advantage in product and process innovation. Rather, patents are not the only way to gain this advantage. For example, a recent survey of U.S. firms in a variety of industries found that lead time, secrecy, and moving down the learning curve quickly (so costs fall as cumulative output and production experience increase) also played important roles in protecting the competitive advantage of an innovation. From a policy perspective, however, government cannot readily provide these other forms of advantage; a firm's learning, secrecy, and production experience must come from within.

FEDERAL FUNDS FOR RESEARCH AND DEVELOPMENT

The Federal Government and the private sector support all stages of R&D, as shown in Chart 6-3. Development expenditures take the largest share of each sector's R&D spending and basic research the smallest. The government's share of national R&D expenditures has varied between 46 and 66 percent, depending on national priorities and the role of Federal R&D in meeting them.

Chart 6-3

Federal and Private Funding of Research and Development

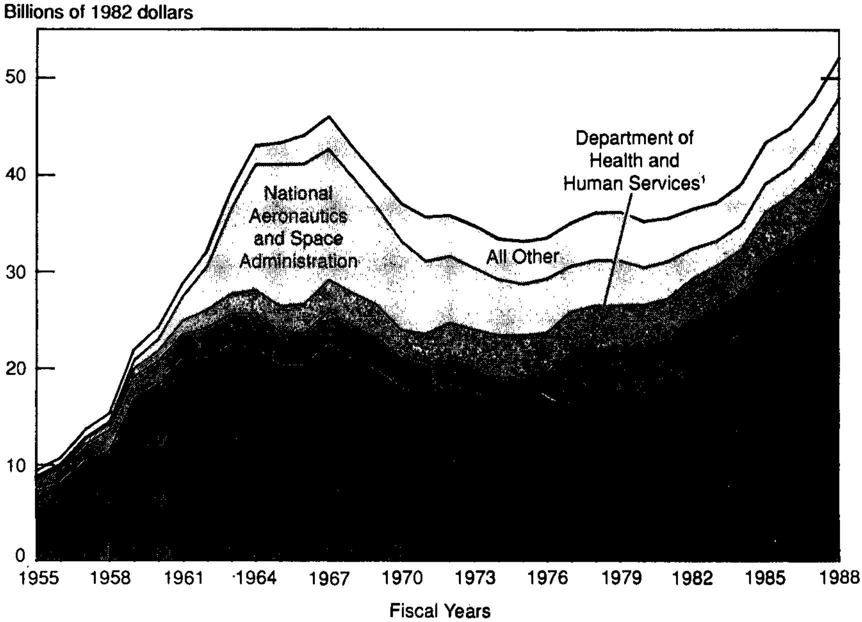


Note.—Private includes a small amount of State and local government funds.
GNP implicit price deflator used to deflate expenditures.
Data for 1988 are estimates.
Source: National Science Foundation.

The level of Federal R&D funding has varied substantially as priorities changed. As shown in Chart 6-4, Federal obligations for R&D in constant dollars declined after 1967 and only recovered their earlier peak in 1987. This slump is attributable primarily to changes in the R&D budgets of the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD), which together accounted for 80 percent of Federal R&D funds in the early 1960s. The rapid growth in Federal R&D began in the late 1950s following the Soviet Union's launch of Sputnik in 1957. High levels of R&D spending supported NASA's successful Apollo program to land a man on the Moon in 1969. While DOD again showed large R&D funding growth during the 1980s as part of this Administration's emphasis on national defense, NASA's R&D funding has not regained its former levels. The Department of Health and Human Services, in contrast, generally showed a slow, steady growth throughout the period. The bulge in R&D funding for the Department of Energy (and its predecessors) during the latter part of the 1970s reflects the ill-advised attempt to seek S&T solutions to the energy crisis and the later efforts of this Administration to cut back expensive demonstration projects.

Chart 6-4

Federal Obligations for Research and Development by Major Agency



[1]Data prior to 1979 are for Department of Health, Education, and Welfare.
[2]Data for 1955-73 and 1974-76 are for Atomic Energy Commission and Energy Research and Development Administration, respectively.
Note.—Data for 1987 and 1988 are estimated.
GNP implicit price deflator used to calculate 1982 dollars.
Source: National Science Foundation.

Although not apparent in agency R&D totals, the recent growth in DOD's R&D has significantly offset the increasing emphasis on basic research in the civilian agencies. Over the past 10 years basic research in the civilian agencies has grown from 23 percent of their R&D to 40 percent. At the same time, however, DOD's share of Federal R&D increased from 45 percent to 67 percent, and DOD spends both a smaller and a declining share of its R&D on basic research. In 1978 basic research accounted for 4 percent of DOD's R&D budget; by 1988 its share had fallen to 2 percent. As a result, Federal spending on basic research remained at 14 percent of total Federal R&D.

Several rationales justify Federal support of R&D. One is that direct government support is appropriate where incomplete property rights lead the private sector to underinvest in R&D; this rationale is the primary economic reason for Federal support of basic research. Another is that the pure advancement of knowledge—with or without some commercial payoff—is worthwhile (this rationale is perhaps best applied to some forms of space exploration). In other cases, social objectives, such as higher levels of education, are furthered by funding for faculty and student R&D. Still another rationale for Federal R&D support stems from the need of the government to use the knowledge.

Relatively small amounts of Federal R&D are funded under the narrow rationale of insufficient private investment in R&D. Taking all basic research as a proxy for that R&D where the private sector has inadequate incentives to invest, about 14 percent of Federal R&D is funded on the basis of this market-failure rationale. If university R&D is the proxy, the proportion is 12 percent of Federal R&D. Instead, as shown in Chart 6–4, most Federal R&D funds go to meet the needs of the agencies themselves. The agencies were created to respond to specific social needs, in such areas as defense, space, and health, where private actions alone would not be sufficient. They rely on R&D to help them meet their goals or to provide them with technologically advanced products where they are the dominant purchaser. In such a situation, R&D is a means of fulfilling the agencies' roles in society; support of R&D is not an end in itself.

FEDERAL TECHNOLOGY TRANSFER

Because of the large direct Federal role in R&D, policy officials have recently paid particular attention to incentives for the transfer of the results of federally sponsored R&D to industry.

Government Patent Policy

Some results of federally funded research are patentable, and government policy on ownership and use of these patents has recently changed to offer greater incentives for their commercialization. The earlier policy of many agencies was to patent their inventions and to provide nonexclusive licenses to encourage wide use of their research results. Agencies found little demand for nonexclusive licenses.

Legislation in 1980 permitted contractors engaged in federally funded R&D to obtain patent title when they are small businesses, universities, or nonprofit institutions. A 1983 Presidential memorandum extended the contractor title policy to firms of all sizes (unless contrary to law) and removed a previous restriction mandating that a Federal agency should normally retain title to inventions that concern public safety, health, or welfare. Amendments to the patent title legislation in 1984 extended its coverage to university and nonprofit operators of government-owned, contractor-operated research facilities and in 1986 to some cases of government-owned, government-operated facilities.

A policy of offering contractors exclusive rights to patents arising from government-sponsored R&D is likely to be the most effective way of ensuring that research results will be brought to the point of private commercial use. Indeed, without exclusive rights, private entrepreneurs are likely to shy away. The post-patent stages of the innovation process may involve substantial investment in additional research that may not be patentable or easily protected. In addition, contractors may have used their proprietary information in carrying out R&D for the government, making it difficult or impossible for another firm to exploit the patent without using that information.

The 1980 legislation permitting universities to own patentable inventions flowing from federally funded research appears to have stimulated both invention and university-industry cooperation. The number of university patents increased from 230 in 1976 to approximately 900 in 1987, of which universities are licensing almost one-third to private firms for development and potential commercialization. Universities attribute the significant increase in business-sponsored research on their campuses to this legislation. Some observers also view the growth in the U.S. biotechnology industry as largely a product of the university-industry cooperation made possible by this legislation.

Cooperative Research Involving Industry, Federal Laboratories, and Universities

Policymakers also recognized the importance of incentives as they tried to improve the linkages between researchers in government laboratories and private industry by allowing laboratories to keep a portion of the revenues from license fees. The Technology Innovation Act of 1980 (the Stevenson-Wydler Act) explicitly promotes civilian technological innovation, by making the transfer of federally owned technology to industry and to State and local governments an objective of all Federal laboratories.

The Federal Technology Transfer Act of 1986 amended the Stevenson-Wydler Act to encourage further the transfer of Federal technology to industry. Federal laboratories could perform cooperative research with outside parties, as long as such research was consistent with the mission of the laboratory, and permit private companies to obtain in advance rights to patent technology developed under the cooperative agreements. The act also provided that laboratory directors could negotiate licensing agreements arising out of other, noncooperative research at the laboratory. It enabled an agency to retain any royalties resulting from commercialization of inventions from its laboratories, and it directed the agency to share those royalties with the individuals responsible for the invention and with its laboratories. Preliminary indications of the effect of these two laws are favorable. Inventions reported by government scientists rose significantly in fiscal 1988 compared with fiscal 1987, and Federal laboratories have entered into almost 100 cooperative research agreements with private companies under the Federal Technology Transfer Act.

The Federal Government has also encouraged new institutional arrangements for cooperative research. These cooperative arrangements have several motivations and objectives, including cost-sharing, reducing the barriers to commercialization of technology developed in universities or government laboratories, making more effective use of the scarce and valuable talent and facilities of government laboratories, and broadening the scope of firms' exposure to external technical advances. As an example of the new institutional arrangements, in 1986 NSF made the first 6 of what has since become a total of 18 awards for Engineering Research Centers located in schools of engineering that also have support from private industry. Based on strong industry and university interest, NSF has developed a similar program for science and technology centers and announced the first 11 awards in December 1988.

Some critics have voiced concerns that cooperative research involving industry and either universities or government laboratories may divert these institutions from their proper social objectives. They fear that university researchers will develop an excessively near-term focus and neglect longer term research, or that government-funded laboratories may be diverted from their primary goals in order to do research on commercially profitable products. But it may also turn out that researchers still do longer term research, although in areas with market potential.

A basic issue raised by concerns over research diversion involves the opportunity cost when researchers cooperate with industry. That is, if researchers are diverted, which type of research has the greater value to society? Some academic research driven purely by the interests of the scientist leads to important breakthroughs. The R&D process does not move in a single direction, however, and basic research is not the only source of ideas. Important feedbacks occur throughout the R&D process; social problems and technological limitations can stimulate major fundamental research. The heart of the issue lies in identifying the effect of cooperative research on the composition and quality of R&D. Two final points are that the sponsoring agency must ensure that government funds are used only to further the objectives of the agency and, for Federal laboratories, that technology transfer is now part of their mission.

A different problem arises from the limitations of relying on researchers alone to become entrepreneurs or product champions. They may not have the skills or interest in turning research results into commercial products. What is needed is industry awareness and anticipation, while the research is being planned, of how the results of longer term, fundamental research could lead to product or process improvements. Cooperative research across sectors can increase this awareness, as industry identifies areas of long-term research in which it will invest.

FEDERAL SUPPORT FOR INDUSTRY

Industry now receives one-half of all Federal R&D funds. The U.S. Government has longstanding relationships with industry in space and defense to meet agency goals. Some observers cite the commercial success of the U.S. aviation industry as justification for Federal support of other industries. But as a counter-example, spillovers from defense research into the civilian sector appear to have fallen off since the 1950s. The underlying question is whether federally funded R&D in industry can both meet government needs and benefit society in other areas as well through its use in commercial products and processes. This question is not easily resolved, and policy officials are still examining existing government-industry relationships and developing new ones to permit broad use of Federal R&D results.

Industrial Base

One troublesome facet of government-industry cooperation becomes evident when foreign competition threatens a U.S. industry that is deemed to be important for national security. This competition may result from unfair trade practices, exchange-rate changes, cost of capital, or superior foreign products or production capabilities. In recent years two examples have arisen of Federal R&D directed at improved manufacturing capabilities for strategically important U.S. industries—machine tools and semiconductors. In both cases foreign competitors undercut the competitive position of U.S. firms, and the industries petitioned the U.S. Government for relief. Both industries directly or indirectly raised national security arguments to support the need for continued domestic production. In both cases the government granted some import relief and supplemented it with support, through DOD, for research to improve the manufacturing capabilities of the industry.

The National Center for Manufacturing Sciences (NCMS), established in 1986, is an R&D consortium focusing on manufacturing technologies of all types. Although U.S. manufacturers of machine tools are involved, membership is much broader, including the users of manufacturing technologies in the automotive, defense, and consumer products industries and suppliers to the machine tool industry. The NCMS contracts out its research to industry, academia, and government. The NCMS receives about $5 million a year from DOD and plans for $45 million a year from private sources.

SEMATECH (semiconductor manufacturing technology initiative) is a newly established consortium of U.S. semiconductor producers, equipment suppliers, and users. SEMATECH is developing the next generation of process technology for the production of semiconductors, where U.S. firms have lost market share to Japan (especially in DRAMs) and for which efficient production processes are critical for commercial success. SEMATECH is partially supported with Federal funds, with DOD authorized to provide $100 million of support in fiscal 1989.

The existence of NCMS and SEMATECH raises fundamental questions about DOD's role in supporting civilian commercial technologies. The Department clearly needs semiconductors and advanced machine tools and, in special circumstances, may not want to rely on foreign suppliers. But DOD's demand for these products is only a small portion of the total market, and DOD alone does not need and cannot support a large domestic production base. Requiring DOD to provide R&D support for an industrial base larger than it needs, however, diverts its resources from military technologies that the private sector would never fund on its own.

Cooperative Research and Development

Cooperative research among competing firms is an organizational form of research that some argue deserves special Federal support. Many firms benefit from cooperative research on generic projects, the argument states, that individual firms lack incentives to finance themselves. Yet the fact that firms share the costs reduces the need for government support. The argument is most convincing where members of the cooperative cannot readily appropriate research results, so that they lack sufficient incentives to invest. For example, incentives to invest could be inadequate if intellectual property protection is incomplete, if the results cannot be kept secret, and if participants will not gain lead time.

Cooperative R&D is an obvious way for companies to overcome the limitations of R&D budgets. It can eliminate purely duplicative research of individual companies and free up resources for additional research. It can marshal more researchers and equipment to work on a problem. Cooperative R&D can also pursue several possible solutions simultaneously, thereby reducing the risk of finding no feasible solution at all.

Formal modes of cooperation are cumbersome to arrange, difficult to administer, and often only modestly successful. Competitors often bring different R&D capabilities and knowledge to a proposed cooperative R&D effort. If participants pool personnel and knowledge, those with the better staff and equipment are often reluctant to join. The participants' ability to exploit the fruits of cooperative R&D projects often differs, which makes the selection of appropriate projects and the optimal sharing of R&D costs touchy subjects.

Competitors can address these problems in several ways. The Microelectronics and Computer Technology Corporation (MCC), a private R&D cooperative established in 1982 without government subsidy, serves as an example. The corporation performs advanced long-term R&D in microelectronics and computer development; it does not develop products or processes. Members do not pool proprietary research and face no restrictions on their own individual research. The private sector financing and governance provide market checks against MCC becoming irrelevant to industry needs and inefficient in its management.

Members of MCC have adopted a simple rule for assigning R&D costs: initial participants in a program pay an equal share; later participants may pay a larger amount. Because of the difficulty of predicting how beneficial some technology will be to a particular member, participants make an additional payment for a license to use a technology coming out of their program, and they share in the royalties. Participants also receive a 3-year head start in access to technologies before those technologies are opened to other MCC shareholders.

Alternative cooperative approaches involve either formal technology licensing or informal know-how trading after the research is completed. Know-how trading takes place when scientific and technical personnel obtain information from colleagues at other firms, possibly competitors, and provide other information in turn, possibly at a different time. The technical participants judge the quality of information given and received and, over time, ensure that exchanges are of comparable value. This phenomenon partially explains the rapid leakage of technology out of innovating firms, and also explains the incentives for firms to fund R&D despite the leakage—they get know-how in return.

Given the many ways in which industry generates and shares knowledge without government support, proposals for Federal support of cooperative industry research should identify the circumstances that make purely private solutions infeasible and the extent to which the social benefits of government support exceed the public costs. Government funding certainly makes a consortium more attractive to industrial participants if the money comes with few strings attached. However, government funding raises such issues as which firms are eligible for membership in the consortium, under what conditions nonmembers can obtain access to the R&D results, when foreign members are eligible for membership, and how scarce government resources should be allocated among various consortia.

Perhaps a more useful and appropriate government role than funding would be to gather information on successful organizational and contractual solutions to the typical problems in cooperative industry R&D. And, where industrial R&D consortia operate in areas where the Federal Government supports R&D, these consortia should be eligible to compete for R&D support on equal terms with other research institutions.

POTENTIAL POLICY PROBLEMS

Some emerging issues pose potential problems for the continued success of the American S&T enterprise; among them are the politicization of the allocation of Federal R&D funds, the degree to which the country benefits from government R&D spending, and the adequacy of the supply of scientists and engineers to meet the needs of the U.S. economy.

Political Pressures in Research Funding

Decisions on R&D funding are increasingly subject to political pressures. These pressures are brought to bear by industries that do not receive Federal R&D funds at the level or in the form they want, by research organizations that do not obtain their "share" or do not receive funds for the specific purposes they want (e.g., facilities), and by regions that want the resources associated with Federal R&D.

The location in which R&D is carried out is not a new concern for science policymakers. For example, the geographic distribution of National Science Foundation grants was an issue in the Congress before the organization was established. However, Federal research funds are increasingly earmarked for particular institutions in the budget and appropriations process, rather than allocated by agency decisions. One estimate showed that earmarked science projects had increased from 19 in the 1979–80 sessions of the Congress to 121 in the 1985–86 sessions, with recipient institutions rising from 12 to 60.

Such political intervention is not surprising; locations in which research is conducted gain from Federal funds regardless of any potential commercial benefits that may result from the research. Earmarking appears to benefit institutions that have difficulty obtaining Federal funds. One study found that the top 20 universities (in terms of Federal R&D support), which got 41 percent of total research funds, received only 1.3 percent of earmarked funds in 1986. Universities ranked below the top 100 received 14 percent of the total R&D funds but 71 percent of earmarked funds, suggesting that research institutions lobby for earmarked Federal research funds that they could not obtain otherwise.

The potential problem is that political earmarking will waste R&D resources. Once the evaluation criteria have been established, researchers should compete on merit—not their lobbying skills.

Access to U.S. Science and Technology

Concerns for both national security and economic competitiveness have generated interest in setting appropriate conditions for foreign access to American S&T. On the competitiveness side, the primary consideration is to ensure that the Nation benefits from its R&D investments, particularly those publicly funded.

Both this Administration and the Congress have sought to balance international S&T relationships through measures that ensure comparable access to government-sponsored or government-supported R&D programs and facilities. All nations should eliminate R&D arrangements that discriminate against researchers based only on their nationality. Comparable access across all countries will not suffice to ensure that research opportunities afforded by such access will be used, however. The degree of use of foreign research opportunities depends on individual perceptions of research-facility quality, the existence of language barriers, the costs of carrying out research abroad, and the individual researcher's expertise. Several U.S. Government agencies are taking steps to increase American use of worthwhile foreign research opportunities. These agencies plan to monitor and provide information on research opportunities abroad, fund more international research, and provide scientists with foreign language training. These measures will benefit the United States as American researchers take greater advantage of the increasingly strong S&T capabilities of other nations. As in trade, solutions to a perceived lack of reciprocity or imbalance should end up helping instead of harming the United States.

Policies to ensure that the United States benefits from its government-supported R&D investments have to take into account the openness of much of the U.S. research system. Academic research is traditionally published, and draft material circulates in informal research networks. Cooperation among nationals of different countries—formal or informal, in U.S. laboratories or abroad—can improve the productivity and quality of the research. Such cooperation benefits all participants. At times, however, participants may be able to appropriate the research results, e.g., through patents, and put them into commercial use. The U.S. Government now includes intellectual property protection provisions in its international S&T agreements to guard against this eventuality.

Strong domestic research cannot ensure that the United States will remain the location of production for goods derived from that research. Once the country has made an R&D investment, it is in society's interest to allow that knowledge to be incorporated into products, wherever they are produced. The best way to ensure that U.S. firms and the American public benefit from this R&D is to give firms a policy environment conducive to innovation.

New Scientists and Engineers

Recent demographic trends have raised doubts about the adequacy of the future U.S. science and engineering work force. The size of the 16- to 18-year-old population of the United States peaked in the mid-1970s, and it is expected to continue to decline until the mid-1990s. Each successive college-age cohort contains a larger proportion of ethnic and racial minorities, which historically have been poorly represented in science and engineering. By the year 2000, more than 25 percent of the college-age population will be black or Hispanic. The math and science performance of U.S. students at the precollege level is relatively poor, whether that performance is measured against other countries or within the United States over time; this showing is a matter of concern. These trends taken together could impose restraints on the supply of newly trained scientists and engineers unless educational and employment patterns change.

The downturn predicted for the number of bachelor degrees in science and engineering based on past participation rates has not yet come about. The United States is already halfway through its demographic decline in the college-age population, and the number of college graduates with first degrees in the natural sciences and engineering (excluding social and behavioral sciences) has continued to increase. Much of this continued production of bachelor degrees in science and engineering is attributable to the increased participation of females and increased enrollments in computer sciences.

Foreign students play a large role in U.S. graduate education, although at the undergraduate level they account for less than 4 percent of the degrees in science and engineering. In 1987, foreign students received 30 percent of U.S. doctorate degrees in science and engineering, up from 21 percent in 1978. Within engineering, foreign students received the majority of U.S. doctorates in 1981, and by 1987 their share reached 55 percent. Two-thirds of these foreign engineering students are from Asia. Students from Taiwan, South Korea, and India accounted for 44 percent of the foreign engineering doctorates in 1987, illustrating the importance of American institutions in training scientists and engineers from developing countries.

The U.S. higher education system has become a major producer of international human capital.

Ability to meet the longer term needs of the U.S. economy for scientists and engineers will depend on the basic factors that affect their supply. One factor is pay for scientists and engineers at different degree levels and compared with job opportunities in nonscience fields. Another factor is the flow of undergraduates, which depends on a supply of qualified high school graduates. Longer term enlargement of the base of potential scientists and engineers also depends on the recruitment of women and minorities into these fields.

CONCLUSION

Because the 1980s have seen strengthened incentives for the private sector to put the results of R&D into commercial use, major changes in the role of the Federal Government do not appear to be needed. Nonetheless, the United States needs to improve its understanding of the factors—institutional relationships as well as incentives—that determine how effectively the S&T system works. The Nation needs to ensure that efforts to benefit particular groups do not hinder the efficient deployment of S&T resources. In this way, the United States can continue to stimulate its scientific and technological genius, which for so long has benefited both the Nation and the world.